Application of Sigma7500 pattern generator to X Architecture and 45-nm generation mask making

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ABSTRACT

The mask cost is increasing substantially from generation to generation. Hence, reducing the mask cost is one of the most critical needs in developing a new generation of technology. Compared with variable shaped beam (VSB) e-beam tools, laser writers have the advantage of higher throughput and lower cost. Moreover, the writing time is not dependent on feature count but on the area written. Additionally the FEP-171 resist, which is used for the DUV laser writer, is also the resist used for VSB writers. This enables process sharing and reduces the number of processes needed for mask manufacturing. Finally the laser writer is expected to print Manhattan and X-architecture features with no major differences. Whereas, VSB e-beam tools takes longer to write, if X features are included with Manhattan-type features. The inclusion of X features also worsens CD uniformity when written with VSB e-beam tools.

The Sigma7500 DUV laser writer uses partially coherent imaging of a spatial light modulator (SLM) to maximize resolution, while providing 4-pass and 2-pass printings, corner enhancement, and grid matching. These functions are evaluated and the results are reported in this paper.

Evaluation data shows that the global CD uniformity of dense line/space and isolated spaces is around 6 nm (3σ) for features at 0-, 45-, 90-, and 135-degree angles, which are used in the X architecture. The resolution of lines and spaces can both reach 150 nm. Based on our evaluation, the Sigma7500 can meet both critical 65-nm and sub-critical 45-nm generation mask specifications and reduces the writing cost by 40%. The writing time for X architecture patterns can be reduced by at least a factor of two as compared to VSB systems, while the CD performance remains comparable. However, the pattern fidelity is slightly worse and the CD of 45- and 135-degree lines is difficult to adjust independently.

In addition, the Sigma7500 comes with a data-sizing function (ProcessEqualizer) to compensate for global CD signatures, but the potential impact of data sizing on OPC accuracy is a concern and it must be evaluated. Evaluation data shows that the Sigma7500 is capable of 45-nm node sub-critical mask production. Its advantages in high productivity and acceptable CD control should provide a solution to reduce the mask cost of advanced nodes.

Keywords: Mask writer, optical mask writer, SLM, X architecture

1. INTRODUCTION

The mask cost increases as the IC industry moves to newer technology nodes at smaller dimension. In practice, it is the consequence of lithography non-linearity, smaller feature size, and the usage of more aggressive OPC, which cause significant increase in the photo-mask write time as the information content in the photo-mask grows【1-2】exponentially through the technology nodes. The long write time, especially for X architecture, seen today on 50kV vector shaped beams (VSB), and the resultant high photo-masks cost, have created significant industry interest in finding a higher productivity and lower cost of ownership (CoO) manufacturing solution【8-14】. For a photo-mask manufacturer, a preferred solution is a tool that can offer both high accuracy and short writing time. Sigma 7500 has been evaluated, and it demonstrates good potential to meet both requirements, while offering the potential in further improvement of throughput without compromising the accuracy.

2. EXPERIMENTAL CONDITIONS

2.1 Material and equipment

In this evaluation, three layouts are prepared for the demonstration of the Micronics Laser System. The layouts consist of 65-nm X-architecture structures; 45-nm inter-metal test structures, and some OPC test patterns. Mask blanks, coated with FEP-171 positive chemically amplified resist (CAR), on top of a thin chrome film are used for the mask writer evaluation[7], with the NTAR7 (730Å) chrome binary masks were optimized for 193 nm lithography. These FEP-171 coated blanks with thin chrome are used for evaluation and comparisons of the VSB and the DUV laser mask writers. HOYA Mask Blanks Division provided all the mask blanks for this study. All patterns were written on a Sigma7500, located at Micronics Laser Systems, using 4-pass writing. The resist thickness is optimized at 320 nm for 248-nm wavelength patterning with the laser writer based on swing curve optimization. In each demo, two patterned masks are delivered from Micronic, one after development inspection (ADI), and the other after striping inspection (ASI), where ProcessEqualizer is applied. The mask process is completed at Micronic’s facility. The post exposure bake (PEB) is carried out using a Steag-Hamatech APB-5000, and a Steag-Hamatech ASE-5000 is used for the developing process. Chrome dry etching is done using Unaxis Mask Etcher III and $Cl_2/O_2/He$ chemistry. All critical dimensions (CDs) are measured by CD-SEM.

3. RESULT AND DISCUSSION

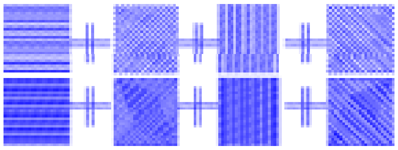
3.1 65-nm generation X architecture pattern

3.1.1 Global CD Uniformity in resist

For Simga7500 DUV laser writer tools, global CD uniformity not only relates to pattern uniformity across an SLM stepper field but also to the variation of focus. Test patterns are X architecture layout, used to measure the CD variation from the optical writer. Table 1 shows the global CDU summary table for 65-nm generation X-architecture pattern in 300 nm thick resist for all four-angled CD, for a dense pattern with duty ratio of 1:1 and isolated space. Comparing with VSB results, the performance is worse, but it can still meet 65-nm generation mask CD requirement.

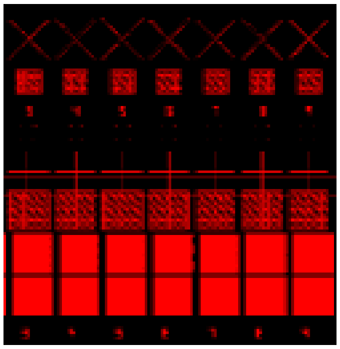
From the dense and isolated pattern results, the isolated pattern has better performance in VSB system because a single shot is used to define the isolate pattern, and the position error is also smaller than the multiple shots which is used to define the dense pattern. However, the Sigma system does not have this problem. Both the isolated and dense patterns show similar performance; because the raster scan system has the same writing strategy for all patterns. The normal and reverse tones behaviors for VSB and Sigma7500 are similar in isolated and dense patterns. Even the global CD uniformity of the Sigma system can meet the 65-nm generation mask requirements. However, for the Sigma7500 it is difficult to adjust angled-CD for 45 and 135-degree lines independently. It is a concern for X-Metal mask making.

Table 1. 65-nm generation Global CD uniformity summary table



Dense pattern

Tool	Angle	0	45	90	135	4ANG GCDU	X-Y difference	4 angle difference
VSB	Mean	353.8	355.8	353.7	355.4	10.2	**0.1**	**2.1**
	GCDU (nm)	**5.5**	**6.5**	**5.3**	**7.7**			
	3Sigma (nm)	3.46	3.79	3.32	4.01			
Sigma7300	Mean	346	342	337.7	341.7	15.92	**0.6**	**1.7**
	GCDU (nm)	**11.2**	**12.3**	**10.6**	**10.9**			
	3Sigma (nm)	5.94	7.54	8.39	6.6			
Sigma7500	Mean	335.75	333.1	333.02	334.11	13.76	**2.73**	**2.73**
	GCDU (nm)	**8.93**	**10.8**	**8.16**	**12.26**			
	3Sigma (nm)	5	6.42	5.39	6.51			

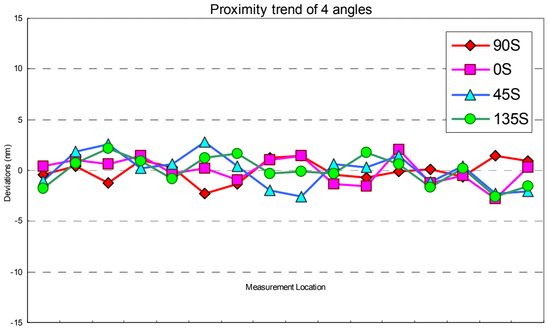


ISO pattern

Tool	Angle	Space				4ANG GCDU	Reverse tone	
		0	45	90	135		0	90
VSB	GCDU (nm)	**4.4**	**4.7**	**4**	**5**	**8.3**	**11.7**	**11.7**
	3Sigma (nm)	2.92	3.06	2.63	3.16		7.97	7.56
Sigma7300	GCDU (nm)	**7.2**	**9.2**	**8.8**	**9.3**	**11.2**	**9.6**	**8.9**
	3Sigma (nm)	4.87	5.54	5.71	5.44		6.15	4.98
Sigma7500	GCDU (nm)	**8.65**	**10.37**	**10.34**	**11.18**	**13.44**	**11.3**	**10.3**
	3Sigma (nm)	5.44	6.72	6.22	5.92		6.13	6.11

3.1.2 Proximity trend of X architecture

As we know, optical writer do not provide functional knobs to adjust for the proximity effect. So the proximity characteristics and trend stability become very important for optical writers. Figure 1 shows the proximity trend of four-angled CD performance. Sixteen-pitch patterns in nine sites are measured. We find that the proximity trend of through-pitch L/S pattern is very flat and consistent within themselves; and the proximity error could be controlled to within 5 nm. This is very important for OPC calculation and compensation in future production. Besides, the totally range of proximity error is around 12 nm, for all angled patterns from all 576 points.



Tool	PRX mean range (nm)				0/90 2ANG GCDU	4ANG GCDU
	0	45	90	135		
VSB	**3.2**	**5.58**	**2.34**	**4.69**	7.9	13.8
Sigma7300	**5.78**	**9.72**	**3.82**	**7.09**	14.03	20.3
Sigma7500	**4.9**	**5.31**	**3.7**	**4.7**	12.56	12.56

Fig. 1. Proximity trend of 65-nm generation X architecture

3.1.3 Brief conclusion

From the 65-nm generation X architecture demo results, most of the items could meet mask CDU specification.

3.2 45-nm generation metal pattern

3.2.1 Global CD Uniformity in resist

We find that the global CD uniformity of the 45-nm generation metal layer on Sigma7500 is similar to that of 65-nm generation demo results; it can meet the 45-nm generation sub-critical mask requirement. In this demo, we will focus on the proximity trend and local CD control capability for machine characterization.

3.2.2 Proximity trend

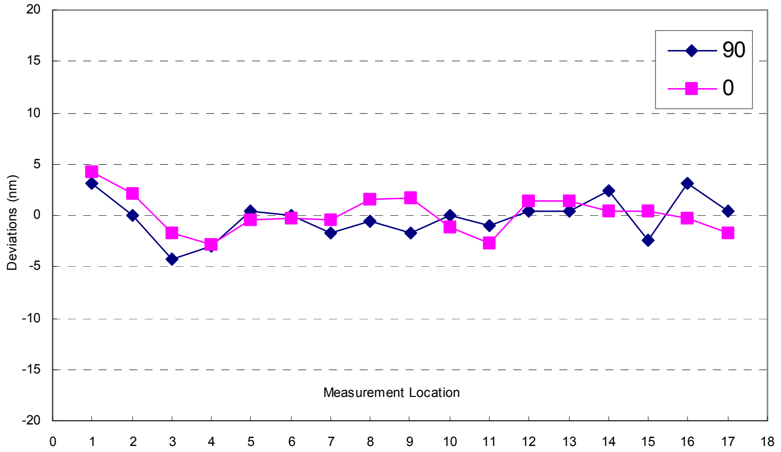
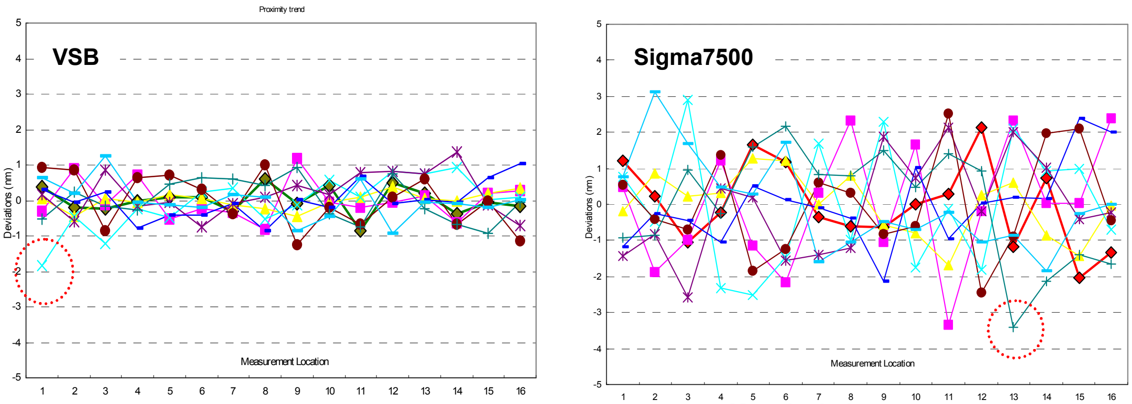


Fig. 2. Proximity trend in 45-nm generation X architecture pattern in two orientations

Figure 2 shows the proximity trend of vertical and horizontal spaces in a 45-nm generation metal pattern. The consistency of these two directions is good, but the range is much worse than that from the 65-nm demonstration. The root cause are (1) The 45-nm generation pattern pitches are much tighter than those from the 65-nm generation (2) The proximity effect is gradually trending up in the dense area. (3) The total range increases to 10 nm. This data indicates that we are driving near the maximum NA of the tool. We expect the next generation tool, with shorter wavelength or higher NA can help to reduce the proximity range.

3.2.3 Maximum CD deviation

We have determined that the maximum CD deviation relates strongly to the local CD performance of the writer in this study. We measured the through-pitch performance across nine sites on the mask. The maximum deviation is determined from the graph, which plots the normalized through-pitch CD difference of each site to the average data of all nine sites. Figure 3 shows the through-pitch maximum deviation of VSB and Sigma7500. As shown in the graph, the e-beam writer has a smaller total range than laser writer. Sigma 7500 shows maximum deviation of 3.4 and 4.0nm in the vertical and the horizontal directions respectively. Data indicates that CDU performance in the horizontal direction is always worse than vertical direction in all our CD measurements, and this might be contributed from the tool optics or writing strategy due to scanning. Furthermore with the VSB system, the maximum deviation is only 1.9 nm, and it indicates that E-Beam has better local CD control capability than laser writer. The maximum deviation is related to local CD control capability and it is a fundamental performance indicator, which directly affects the mask quality.



Max deviation = 1.9 nm

Max deviation = 3.4 nm

Fig.3. Maximum deviation comparison between VSB and laser writer

3.2.4 Brief conclusion

Sigma7500 can be further improved to meet 45-nm generation mask specification.

3.3 Pattern fidelity and resolution in chrome

The main drawback of optical writer is that the resolution and pattern fidelity is lower as compared to VSB e-beam tools. To overcome these problems, the Sigma7500 DUV laser writer uses 248-nm wavelength and corner enhancement technology to improve the pattern fidelity[8-9]. Figure 4 shows the CD-SEM top-down view of pattern fidelity in the chrome film. The contacts hole size can be patterned down to 200 nm, but it is showing serious corner rounding. However, the resolution of an isolate cross mark pattern is as good as 150 nm. It could meet the minimum feature size requirement for the 45nm node. However, the resolution, proximity trend and two-dimensional pattern fidelity are worse than VSB systems. It means that the OPC model needs to be re-tuned for production with the optical writer.

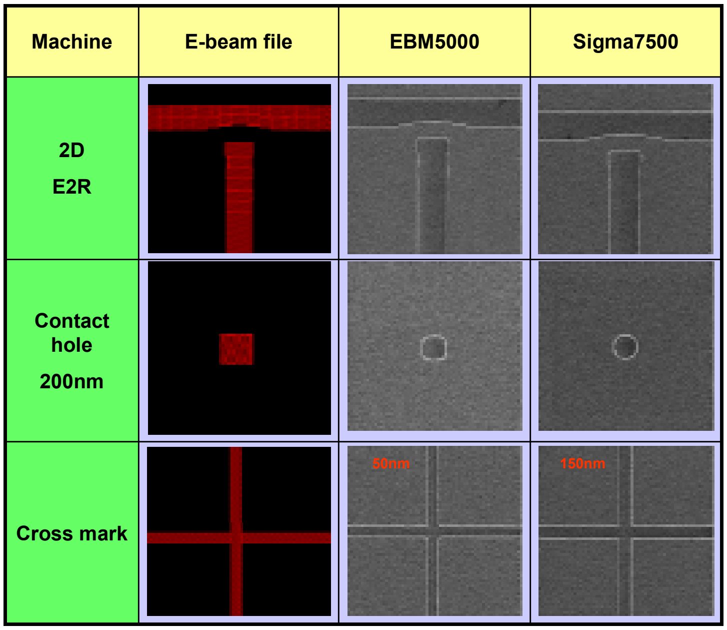


Fig.4. Pattern fidelity and resolution for three different mask writers

3.4 Luminescent pattern evaluation

An emerging new OPC technology, the Luminescent OPC software, is also studied in this paper from the mask making perspective. We compare the pattern fidelity and throughput for different segmentation lengths using both VSB and Sigma7500 systems. Figure 4 shows the pattern fidelity of Luminescent converted patterns, which are processed using 15 and 40 nm segments. The VSB pattern fidelity is much better than Sigma7500, however this is may not be the major concern from the perspective of wafer processing window. Besides, no matter the VSB or Sigma7500 systems, the dimension for these patterns is very difficult to measure with CD-SEM. A different qualifying index will have to be set for these special patterns. As for impact from the writer, Table 2 shows the throughput comparison. We find that the throughput of the VSB writer depends strongly on total shot numbers, while the writing time of Sigma7500 is much shorter than VSB system and the throughput is almost the same for all segment lengths. It is a great advantage of laser writers is this complex OPC application.

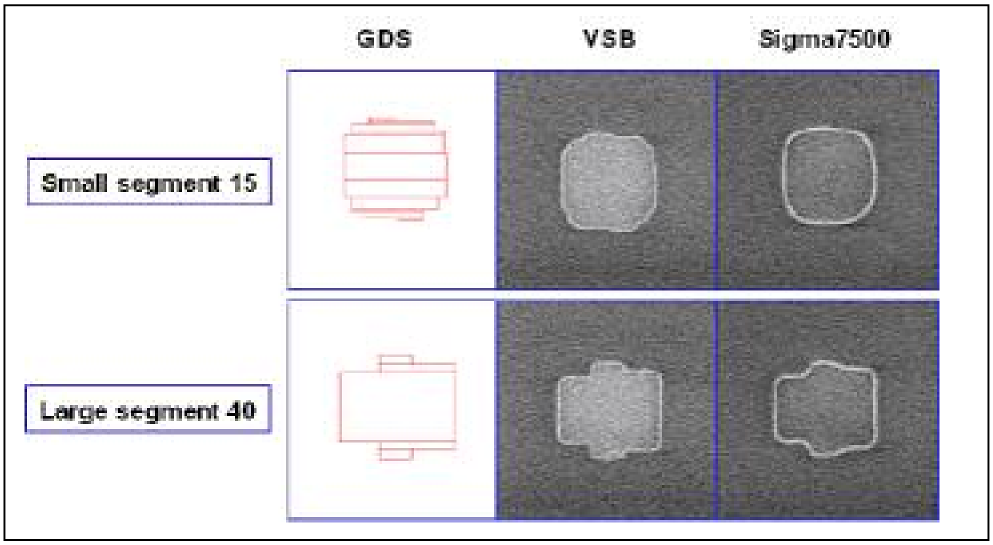


Fig. 5. Pattern fidelity of Luminescent converted contact holes.

Table 2. Throughput comparison

Layout	VSB	Sigma7500
Luminescent_F15	7h 55m 41s	3h 40m 57s
Luminescent_F20	5h 47m 36s	--
Luminescent_F30	4h 57m 57s	--
Luminescent_F40	4h 36m 16s	3h 40m 19s

4. CONCLUSIONS

We have compared variable shaped beam (VSB) e-beam tools to a laser writer. The latter exhibits advantages of higher throughput and lower cost. Furthermore its throughput is only dependent on the mask writing area and not impacted by various feature patterns, such as 45-degree features or arbitrary complex OPC patterns. This flexibility and predictability is key to its applications in advanced node mask making. In terms of pattern fidelity, this machine can meet both 65-nm and 45-nm generation sub-critical mask requirement. We will need to further understand its reliability and cost of operation in high volume production environment as compared to the e-beam system.

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